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I. Introduction

We were charged in essence with the problem "Is something wrong with C/M and if so, what?"

The first step in coming to grips with this question is to agree to methods for evaluating the system. Since the end result is a photographic image we must construct an objective quantitative measure of image quality. Against this standard the performance of the system must be measured and the observed image compared with the one to which the system is designed - including effects of atmosphere, image motion and film processing and sensitivity in addition to the lens system.

If all of these factors are fully understood and the design performance is achieved, then we conclude C/M is a satisfactory system in the sense we have given it a test and it has passed. There is a big question of course: have we given the right test, i.e., the most useful one from the viewpoint of the mission we want C/M to accomplish? In more specific terms we speak of the optical transfer function or the sine wave response curve t (k) as a function of spatial frequency k as the most convenient meeting ground between design and performance. In the engineering design of an optical system one seeks maximum resolution in lines/mm by keeping t (k) as large as possible in the region of high k.

It is the primary concern of this Committee to determine to what extent the design t (k) is achieved by the system in practice. On the other hand, there are users' criteria of quality and one might benefit for intelligence purposes by trading off, for example, some resolution in order to achieve higher contrast - this is a human factor involving the PI's. This question of the optimum design of a transfer function for the intelligence community is a corollary and also vital problem.

We discuss first in this report ~~The first section of our report is devoted to~~ the question of constructing an objective measure of image quality that is both useful and experimentally feasible. In practice, in the real world, there are many parameters affecting the performance which cannot be precisely specified. The transfer function, t (k), is a product of four components

$$t\,(k) = t_{\text{atmosphere}}\,(k) \quad t_{\text{image motion}}\,(k) \quad t_{\text{optics}}\,(k) \quad t_{\text{film}}\,(k),$$

and uncertainties in these individual factors make it impossible for us to say that the system passes any test perfectly. [We also recognize that this characterization of performance by t (k) is incomplete since granularity is not taken into account. In these discussions we assume the slow, fine grained film 4404 now in use is a fixed parameter of the system.] Rather we must content ourselves by reporting it to perform within a certain quality range. The more we can sharpen up the individual factors the more precise will be our understanding of the system. This calls for a Measurement Program - which is the next main subject of discussion in this ~~Section II of our~~ report. Engineering passes over known design targets in known weather conditions are one aspect. Another very important one is an in-flight measurement program to determine, for example, what the effect of the in-flight environment is on the optical focus - one area of particular concern being the possible focal errors introduced by thermal gradients and transients in the camera barrel and lens system. We do not here attempt a detailed design study but we indicate the types of measurements felt to be most desirable and which can be made on ground or in orbit without substantially conflicting with the operational goals of the C/M missions.

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As a general remark we add our very strong conviction of the need for instituting with great urgency a program of mission measurements and analyses to help identify the causes degrading most of the image quality obtained thus far - or to verify by establishing a lack of corrleation between the image quality and the monitored parameters that the present quality is typical of what is to be expected.

In view of the extremely limited technical feedback as to the performance of components in flight to the systems designers, it is amazing to those of us on the "outside" how well C/M has done so far. Nevertheless, there are major performance variations which follow no understood pattern from one mission to the next. In its best moments C/M has performed very well, indicating that improvements to a higher level of reliability should be possible. The urgency of a measurement program and of timely systematic performance analyses to enable the designers to achieve possible improvements cannot, therefore, be overemphasized in this report!

II. Outline of Report

A. Objective Measures of Image Quality

1. ~~Discussion of~~ Edge measurement techniques for determining the optical transfer function.

The aim here is to provide a reliable and reproducible "canonical" technique for accurately measuring t (k) particularly for high spatial frequencies (say 10 ft ground resolution or 100 L/mm). We want to know t (k) for two reasons. By comparing the measured t (k) with the value to which the system is designed we can hope to answer whether the photography obtained is all that ~~we~~ can be expected from C/M or whether there is a loss of resolution due to shortcomings of the system. Since the atmosphere's transfer function enters into this comparison it too must be measured or calculated ~~xx~~ in principle. As discussed further in Section D the only significant ~~xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx~~ effect of atmospheric haze on C/M photography is a DC reduction of contrast and t(k) is independent of this and therefore of the atmosphere. ~~Section xx~~ A second major reason for finding t (k) is to determine ultimately the trade off between resolution, say in L/mm, vs film graininess, vs contrast measured by $D_{max} - D_{min}$ when it comes to optimizing a system with regard to the users' ability to gain intelligence value from the photography.

The practicability of microdensitometric edge measurements for a routine evaluation of photography at high resolution in order to determine t (k) must still be established. As a relatively new technique it is still fraught with practical difficulties and potential dangers. It presents no theoretical problems, however. Suitable edges for the scale of C/M photography are found in nature in the form of large airfield landing strips and for special tests can be conveniently provided by a target layout on the ground.

In order to demonstrate practicability of edge measurements for 100 Lines/mm analysis a long-range industrial program is in progress and full support to continue and expand it is recommended. Its development goals should be to

1) Establish reliability by comparing recent measurements of t (k) from edge scans to results from sine wave targets. The resulting modulation transfer function should be combined with a film modulation threshold curve to predict the resolution in Lines/mm for direct experimental comparison.
2) Compare and standardize different μ-densitometer slits, determining optimal dimensions and data handling methods.
3) Determine practicability of the method in terms of number of man-hours involved per edge for a reliable scan.

Toward these ends we recommend that there be

a) Initiated both at Westover and NPIC a program of selecting and measuring edges on new mission material (and on past material if warranted by success of the above program) both to advance the confidence in and reliability of edge measurements and to accumulate data on C/M performance.

and b) Constituted a working group including representatives of principal laboratories to carry out a standardization study on edge measurement techniques. This activity should not be bound by security restrictions but should operate as an industrial cooperation oriented by a work statement for such a study from this Committee.

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2. Visual comparison of photography of unknown quality with photography of known quality as obtained by the same optical system.

This technique of subjective quality comparators or "GEMS" (Graded Estimated Measuring Samples) for judging image quality is of great interest because there are no standard resolution targets in operational photography and the edge scan measurements are still of uncertain merit. Moreover comparative analysis of properly prepared GEMS may provide some valuable input into a human equation for the optimum photography for use of the intelligence community.

The first use of such photographic comparators is for engineering evaluation. They will be designed to permit the observer to identify the main characteristics of quality degradation in the actual picture - whether due to reduction of t (k) for high k leading to fuzzy edges of high contrast, or non-optimal processing to high or low average densities which affects graininess, or loss of contrast resulting from corona discharge, light leaks, haze, or thin clouds in the presence of which the edges remain sharp. The observer will identify these quality characteristics by comparison with a library series of GEMS that can be brought to adjacent positions in sequence by a comparison eyepiece. He can also rate the photography by a resolution level in L/mm for 2:1 contrast targets as imaged in the GEMS.

The second use would be to determine the effects of the variables introduced into the GEMS on the value of photographic material for intelligence purposes. To reiterate an earlier point - our primary Committee concern is to determine how well the system produces its design transfer function, but the question of what the transfer function to which the system is to be optimally designed is a longer-ranged and corollary question, and is discussed in the technical sections.

A comparison technique for assessing the photographic quality is presented and the basic elements of a GEM library are discussed in this report. As a first step in implementing this program a simple dual microscope system with a comparison eyepiece and a small library of GEMS with varying resolutions has been prepared.

3. <u>First results of Edge Scan Measurements and visual photographic comparators applied to operational photography</u>.

Edge scan measurements on mission photography have been made with the Eastman Kodak μ-densitometer as summarized in Figures 1, 2, and 3 where the resolution in L/mm is computed from the measured transfer function for 2:1 contrast targets.

GEM measurements of the limiting resolutions of scenes in the close vicinity of these edge scans were made and the correlation with the edge scan results shown in Figure 4. That no better than a moderate degree of correlation was found indicates the extreme caution with which these first results must be viewed.

The 77 frames of Mission 9056 which were given subjective MIP (Mission Information Potential) ratings at NPIC and as discussed and plotted by [redacted] STAT caused very great concern, were compared with the GEMS as shown in Figure 5. A lack of correlation is evident - as it is also with the RES (Reciprocal Edge Spread) measurements made at Westover (Figure 6). [Note moreover that the GEM ratings place 93% of the frames in the 53-105 l/mm range] Furthermore, these two different subjective measures of quality, RES and MIP, fail to correlate with each other as shown by Figure 7. The conclusion from this is that both MIP and RES measurements have a presently uncertain, if indeed any, quantitative value. The GEM and edge scan measures show some promise but conclusions at this time would be premature and the question of C/M's performance is still to be decided by continued analyses by edges and scans and GEMS. Mission 9062 is now being analyzed by edge scan and GEM ratings.

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B. Measurement Program

1. In-flight measurements for obtaining engineering data to check on system performance in the operational environment and to correlate with image quality.

The C/M system is subjected to extensive laboratory tests on the ground in Boston, Palo Alto, and Vandenberg to check its operation both before and after thermal and pressure changes, in different gravity orientations, and after vibrations. These tests are designed to cover the range of parameters anticipated during launch and orbital phases and focal settings must still be within rigid tolerances.

There is no way of knowing, however, that focal errors resulting from thermal gradients and transients do not degrade actual system performance in flight. No in-flight measurement program exists for determining the temperature inhomogeneities during flight due to sun angles and camera barrel exposure to space, and furthermore, there is no in-flight verification that the focal point is at the film. Remedies for these deficiencies are proposed. They require a continuing in-flight measurement program not seriously interfering with operational activities.
and designed to locate focal point relative to film and measure the lens temp.
Furthermore, a vigorous and more thorough laboratory study with a theoretical model is encouraged to complement this program, providing more details as to where to put temperature sensors on board and pointing the way toward improved thermal control.

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Another recurring plague of C/M photography is corona discharge. Laboratory tests suggest that if the ~~These are indications that if the vehicle, and~~ ~~hence~~ film, were maintained at a pressure of 20μ to 100μ instead of at ambient this condition would be controlled. Work is in progress to develop such a light weight pressure system and should be pressed with full support. In view of the recurring serious corona problem a suitable system for maintaining pressures above 20μ, even if not an optimal one, should be introduced in C/M as soon as possible, along with periodic pressure monitoring.

Additional ~~Further~~ ~~elaborate~~ ground tests over a broader range of parameters for checking film flatness are suggested. These should include a broad temperature range and should be designed to test vibration and post acceleration effects.

Direct tests on film properties and sensitometry are discussed in Section C.

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2. Engineering passes with daylight photography of design aerial targets.

It is recommended that these be carried out and the present program extended until one is driven to the conclusion that the system is working up to its design potential. Simultaneous recording of component performance in the measurement program described in the preceding section is necessary to permit degraded imagry to be correlated with faulty components. The resulting loss of operational coverage resulting from such a program is both insignificant and a very worthy investment.

A minimal aerial target is designed which permits determination of the transfer function t (k) from edge measurements on the scale of C/M photography as well as for any system of comparable or superior resolution. This determination is independent of any DC reductions of contrast such as may be caused by light leaks, corona fogging, or atmospheric haze.

In view of the recurring serious corona difficulties and light leaks engineering checks on these factors are also desirable, ~~and may be obtained in either or both of two ways.~~ A direct measure of the reduction in contrast resulting from haze is ~~pos-~~ recommended ~~sible if~~ using a "trusty" recoverable camera, ~~is~~ flown in an aircraft at high altitudes over the target of known ground contrast at approximately the same time as the satellite engineering pass. Relative merits of filters and of different slit widths could also be assessed by such a program.